



Space Shuttle Program

# Shuttle Environmental Assurance

Prepared by:

The Shuttle Environmental Assurance Initiative

Submitted by:



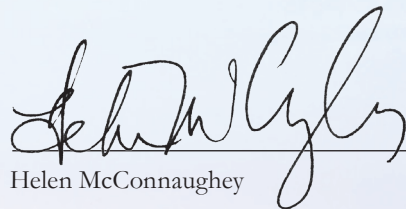
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Steve E. Glover

SEA Lead

*Propulsion Systems Engineering and Integration, MP71*

Approved by:



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Helen McConnaughey

Manager

*Propulsion Systems Engineering and Integration, MP71*



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## Executive Summary

The Shuttle Environmental Assurance (SEA) Initiative provides an integrated approach for the National Aeronautics and Space Administration (NASA) Space Shuttle Program (SSP) to promote environmental excellence, proactively manage environmentally driven materials obsolescence, and optimize associated resources. SEA's primary role is to support mission execution through the life of the Shuttle by identifying materials that may become obsolete as a result of environmental, health and safety (EHS) regulations and to work as a team to mitigate these risks. SEA also supports NASA in its goal of assuring that NASA meets its Federal stewardship responsibilities and attains sustainability.

The SEA Team is composed of representatives of the SSP flight elements, ground operations, flight crew equipment (FCE) elements and contractors, as well as other key organizations with expertise in environmental regulations and impacts, pollution prevention (P2), materials obsolescence, and materials replacement technologies. The Marshall Space Flight Center (MSFC) Propulsion Systems Engineering & Integration (PSE&I) Office manages SEA.

This report summarizes the SEA Team efforts for calendar year (CY) 2004.

SEA tracked environmental and safety regulatory activities and coordinated integrated technical input for those activities having potential SSP operational impact. SEA also coordinated the reporting activities required for the SSP to continue use of hydrochlorofluorocarbon (HCFC) 141b, under the current United States Environmental Protection Agency (USEPA) exemption.

The SEA Team interfaced with other SSP and NASA organizations, as well as with other Agencies and industry groups, to share information on regulatory impacts and materials replacements. SEA worked closely with the NASA Headquarters (HQ) Environmental Office, the NASA Acquisition Pollution Prevention (AP2) Office, and the HQ Air Force Space Command (AFSPC).

During CY 2004, SEA worked on the 17 technical issues shown in table E1. These issues are related to materials that pose an obsolescence risk to the SSP or a potential health risk to SSP workers.



Table E1. SEA issues.		
SEA Issue	Elements Affected	Status
HCFC 141b blowing agent	External Tank (ET), Solid Rocket Booster (SRB), Orbiter, Reusable Solid Rocket Motor (RSRM)	The SSP holds an exemption from USEPA that allows the use of HCFC 141b on ET, orbiter, and SRB through CY 2009. SEA worked with USEPA to add the RSRM use to this exemption.
1,1,1-Trichloroethane (TCA) elimination (orbiter use)	Orbiter	TCA has been stockpiled at Kennedy Space Center (KSC) for orbiter use. The orbiter has screened potential alternatives.
TCA elimination (RSRM use)	RSRM	The RSRM had an exemption for continued purchase of TCA through CY 2004. The RSRM purchased enough TCA to support critical applications through the end of the program and is stockpiling the material.
Cadmium (Cd) replacement in plating applications	ET, Orbiter, RSRM, Space Shuttle main engine (SSME), Ground support	SEA is finalizing a study that assesses the risk and makes recommendations for mitigation.
Hexavalent chromium (CrVI) replacement in conversion coatings	ET, Orbiter, SRB, SSME, RSRM, FCE, Ground support	The SRB has implemented a chrome-free conversion coating. The orbiter and ET are evaluating alternatives. SEA is finalizing a study that assesses the risk and makes recommendations for mitigation.
CrVI replacement in primers	ET, Orbiter, SRB, SSME, RSRM, FCE, Ground support	The SRB has implemented a chrome-free replacement primer. The other affected elements continue to seek replacements. SEA is finalizing a study that assesses the risk and makes recommendations for mitigation.
CrVI replacement in alkaline cleaners	ET, FCE	The ET is evaluating an alternate material.
Chemical paint stripper alternatives	Orbiter	The orbiter is continuing to test alternatives and is also evaluating a portable laser coating removal system.
Alternate dry-film lubricant (Lube-Lok®)	SRB	The SRB is testing a replacement for Lube-Lok®. A qualification plan has been approved.
High-volatile-organic compound (VOC) coatings	ET, Orbiter, SRB, RSRM	The SRB has qualified a replacement. Orbiter replacement is in progress. The ET is testing alternate low-VOC primers.
Hypalon paint	SRB, RSRM	The SRB is testing a perchloroethylene-free version of Hypalon paint. Qualification is planned for CY 2005 and implementation is planned for CY 2006.
Lead-free electronics	Orbiter, SRB, RSRM, SSME, FCE	The SSP projects have been notified of this issue. The orbiter and KSC Logistics have sent notices to vendors. FCE is testing components.
Hazardous air pollutant (HAP) inks	Orbiter	The orbiter is evaluating candidate replacements.
Cleaning and verification solvents	Orbiter, ET, SSME	The ET has implemented HCFC 225. The orbiter has implemented several replacements and work is ongoing. The SSME has also implemented alternatives.
Methyl ethyl ketone (MEK) replacement	Orbiter, ET	The SSP elements have worked on MEK replacements over the past 10 years and plan to address potential replacements as they emerge.
Perfluoroalkyl sulfonates (PFAS)	Orbiter	The orbiter has implemented replacements.
Brominated flame retardants (BFR)	Orbiter, SRB, RSRM, SSME, FCE	The SEA Team is tracking regulatory activities involving BFR and has begun to identify potential impacts to the SSP.

The SEA Team is completing a study and developing recommendations to address the replacement of CrVI in primers and conversion coatings and Cd in plating applications. The likelihood that these materials will become obsolescent and affect Shuttle processing will increase as the program nears termination and then decrease as the last hardware is processed. Risks for new vehicles, especially a Shuttle-derived vehicle, will increase over time. The benefits of replacing these materials include avoidance of the obsolescence risk, a reduction in occupational exposure and risk, and a reduction in hazardous waste streams and the associated costs. Future vehicles will also directly benefit from CrVI and Cd replacement studies because these materials may not be available for use on new NASA vehicles. Costs of replacement will include the cost of screening potential replacement materials, down-selecting viable candidate(s), and qualifying the alternative material(s) for flight.

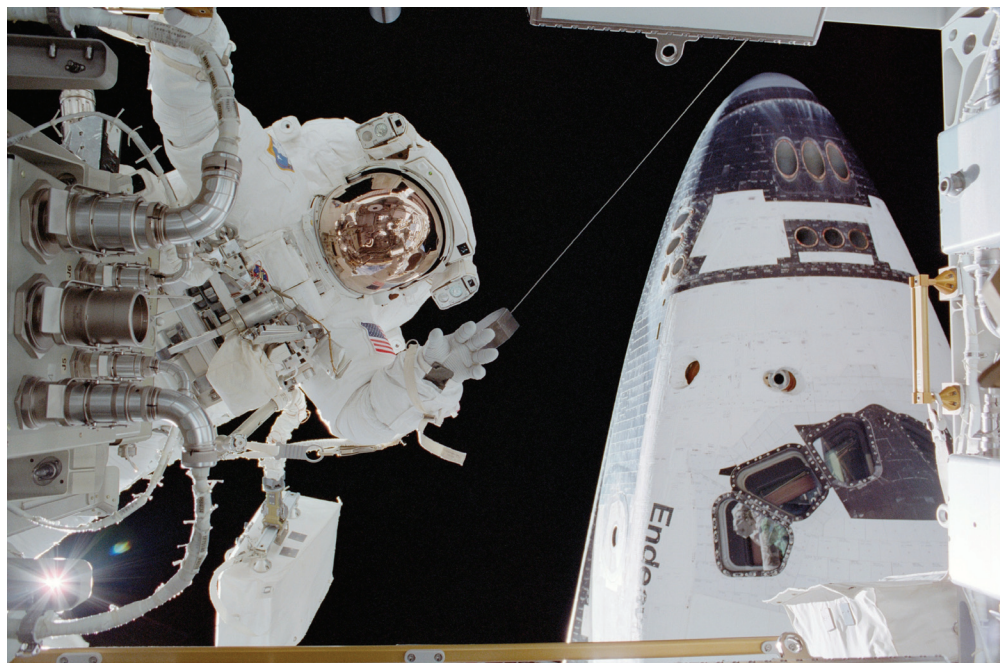
SEA Team members reported a number of pollution prevention successes in CY 2004, including receipt of a USEPA Stratospheric Ozone Award, use of a liquid nitrogen process at KSC to cut materials and remove coatings, and the KSC Chemical Commodity Reutilization Program.

SEA was involved in or tracked other materials replacement projects being done in collaboration with the Joint Group on Pollution Prevention (JG-PP) and the AFSPC. These projects include a portable laser coating removal system, low-VOC and nonchromate coatings systems for support equipment, alternatives to aliphatic isocyanate urethanes on structural steel, alternative low-emission surface preparation/depainting technologies for structural steel, lead-free solder, environmentally preferred coatings for launch structures, fiber optic detectors for hydrazine, and microwave technology to treat hypergolic fuels.

The SEA Team provided recommendations to SSP management regarding strategic planning for the termination and transition of the program by identifying environmental concerns and requirements that, if addressed

early, can reduce the final costs and liabilities. The SEA Team also provided lessons learned to NASA and new vehicle programs to help avoid some of the costs and risks associated with current and emerging environmental regulations.

SEA has benefited the SSP by providing notice and technical support concerning vendor changes and materials concerns, sharing material replacement data and working mitigation efforts, bringing potential issues and risks to management and other technical forums, interfacing with the Department of Defense (DoD) Services, and working with regulators to minimize the adverse impact of regulatory restrictions on the SSP and maintain essential use exemptions.





# 1. Introduction

SEA is an SSP team that works to promote environmental excellence, proactively identify environmental regulations and other potential drivers of materials obsolescence, and facilitate cost-effective mitigation of the resulting risks. SEA members work together to exchange information on pollution prevention and data on replacements for such materials as ozone depleting substances (ODSs), HAPs, VOCs, and heavy metals.

During CY 2004, SEA Team members supported Shuttle return-to-flight activities. The longer term priorities of the SEA Team continued, but progress in some materials replacement activities was impacted due to return-to-flight work. SEA plans a vigorous effort in the coming year to support Shuttle safety and supportability and a safe return-to-flight.

This report summarizes the SEA Team efforts for CY 2004.

## 2. Shuttle Environmental Assurance Initiative

### Shuttle Environmental Assurance Role

SEA's primary role is to support mission execution through the life of the Shuttle by identifying materials that may become obsolete as a result of EHS regulations and to work as a team to mitigate those risks. SEA helps maintain essential use exemptions (EUE) and supports regulatory reporting efforts. SEA also supports NASA in its goal of assuring that NASA meets its Federal stewardship responsibilities and attains sustainability.

SEA provides recommendations to the SSP in its planning for the termination and transition of the program by identifying environmental concerns and requirements that, if addressed early, can reduce the final costs and liabilities associated with program termination. Through its interfacing efforts, the SEA Team is also providing "lessons learned" about costs and risk mitigation strategies related to compliance with current and emerging environmental regulations to NASA and the new vehicle programs.

### Shuttle Environmental Assurance Team

The SEA Team is composed of NASA and contractor representatives of the SSP flight and ground operations elements; representatives of other NASA organizations with expertise in environmental regulations and impacts, pollution prevention, materials obsolescence and materials replacement technologies; and other Federal Agencies. Appendix A is a list of organizations that make up the SEA Team. The MSFC PSE&I Office manages the SEA Team.

## Environmentally Driven Obsolescence

Environmental and safety regulations affect all aspects of Shuttle processing. One consequence of increasingly restrictive safety and environmental regulation is the potential loss of materials and vendors because chemicals are banned, become too expensive to make or use, or the quantity required by the Shuttle is so small that vendors can no longer justify continuing to produce it. Restrictions on the use of ODSs, HAPs, VOCs, heavy metals, and other hazardous materials often affect materials used in Shuttle processing or vendors that supply parts and materials.



## Shuttle Environmental Assurance Approach

**Regulatory Management:** SEA takes a proactive approach to identifying and influencing emerging environmental and safety regulations that may affect materials and processes used in the SSP.

**Communication and Interfaces:** The SEA Team functions as a forum for members to identify and discuss current and future materials replacement concerns and to facilitate discussions with non-SSP NASA organizations and other government entities.

**Technical and Systems Focus:** SEA's primary focus is on materials obsolescence issues that have environmental drivers and affect multiple elements. SEA also addresses other materials, environmental, and pollution prevention issues with the potential to affect individual elements, multiple elements, and the SSP as a whole.

**Risk Management Approach:** SEA uses a continuous risk management process to identify, analyze, plan, mitigate, track, and control each issue. Mitigation plans are developed and implemented for identified issues, with an emphasis on issues that present high or medium risks.

**Collaborative Work:** The SEA Team shares data and information on materials replacements and works cooperatively with other federal agencies and industry on issues that affect the SSP and other NASA programs.

### 3. Regulatory Management

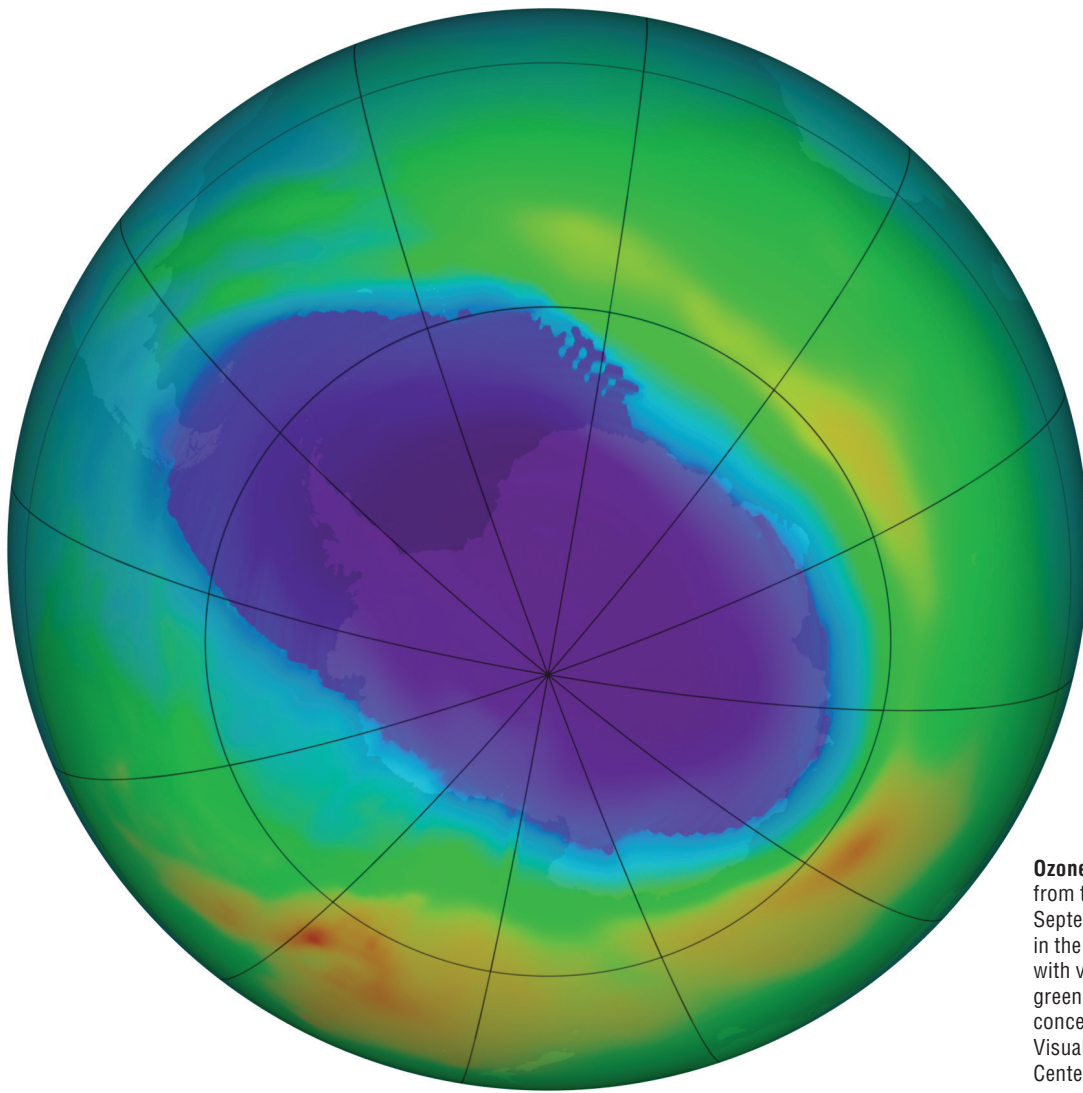
EHS regulations can have major impacts on Space Shuttle operations (table 1). Some materials used in the Shuttle have been banned from production and others have been subject to increasing regulation making their use by vendors cost prohibitive. European and Japanese regulations are also beginning to indirectly affect the Shuttle because vendors must meet these requirements to do business in international markets.

SEA takes a proactive approach to identifying and influencing environmental and safety regulations that may adversely affect materials and processes used in the SSP. SEA evaluates current and emerging regulations for operational impact, participates in the regulatory process, advocates for special regulatory considerations when appropriate, and supports ongoing reporting requirements for SSP materials. The SEA Team reviews the semiannual regulatory agendas and regulations published and proposed by the USEPA and Occupational Safety and Health Administration (OSHA), Executive Orders, and international environmental trends.



Table 1. Major types of operationally-relevant laws and regulations.

Laws	Related Regulations
Clean Air Act	<p>National VOC Regulations and Control Techniques Guidelines (CTGs) Establish requirements for VOC regulations that can restrict usage of volatile organic materials in certain polluted areas.</p> <p>National Emission Standards for Hazardous Air Pollutants (NESHAPs) Industry-specific regulation that can restrict usage of particular materials in specific applications.</p> <p>Phase-out of ozone depleting compounds Regulatory driver for SSP replacement of Freons, halons, TCA, and HCFC 141b.</p>
Clean Water Act	<p>Effluent guidelines Can indirectly affect materials usage by restricting allowable waste water composition.</p>
Toxic Substances Control Act	<p>Significant new use rules (SNUR) Can affect availability of materials by limiting their domestic manufacture or importation.</p>
Resource Conservation and Recovery Act	<p>Hazardous waste definitions and requirements Could change the types of materials SSP must consider hazardous waste, affecting waste streams and disposal costs. Can also affect materials availability if vendors find imposed requirements too costly or onerous.</p>
Occupational Safety & Health Act	<p>Permissible exposure limits (PELs) Reductions in PELs can increase the amount of personal protective equipment required for workers. There is also a need to change processes due to OSHA's stipulation that engineering controls are to be the first line of defense. Any process changes will cause an increase in cost and can result in the unavailability of certain hazardous materials.</p>
Executive Order 13148, Greening the Government Through Leadership in Environmental Management	<p>Presidential requirement that each Federal Agency ensure that all necessary actions are taken to integrate environmental accountability into day-to-day decision-making and long-term planning processes. The order mandates implementation of environmental management systems, reduction of hazardous and toxic materials, and proactive pollution prevention activities.</p>
European Union Directives	<p>Waste Electrical and Electronic Equipment (WEEE) This is a European Union (EU) directive on waste electrical and electronic equipment. It aims to reduce the amount of electrical and electronic waste disposed in landfills and incinerators.</p> <p>Restriction on Hazardous Substances (RoHS) This EU directive requires that, from July 1, 2006, electrical and electronic equipment will not contain lead, Cd, mercury, CrVI, or BFRs.</p>
Montreal Protocol	<p>International agreement phasing out the production and consumption of materials that deplete the Earth's stratospheric ozone layer. In the United States (U.S.), this agreement is codified into law in Title VI of the Clean Air Act Amendments of 1990, and implemented in various regulations, such as those phasing out ODSs and limiting the types of materials that may be substituted in ODS applications.</p>



**Ozone Hole over Antarctica:** This image was acquired from the Aura Earth Observing System satellite on September 22, 2004. It shows depleted levels of ozone in the stratosphere over Antarctica. Purple shows areas with very low ozone concentrations, while turquoise, green and yellow show progressively higher ozone concentrations (NASA image courtesy of the Scientific Visualization Studio at the Goddard Space Flight Center).

## Reporting on Hydrochlorofluorocarbon 141b Use

In 2003, the USEPA phased out production of the ozone depleting substance HCFC 141b. HCFC 141b is a component of the thermal protection system (TPS) on the ET, orbiter, SRB, and the RSRM. As a result of extensive negotiations conducted between SEA members, NASA HQ, and the USEPA, the SSP holds an Exemption Allowance for continued production and use of HCFC 141b in thermal protection foams. The Exemption Allowance requires the SSP to submit three reports to the USEPA annually: Semiannual reports of HCFC 141b usage due on January 31 and July 31 and a petition renewal due October 31 of each year. SEA coordinates and integrates the SSP reporting activities and completed the required reporting in CY 2004. SEA successfully obtained approval for the CY 2005 exemption allowance. The current exemption applies to HCFC 141b use by the ET, orbiter and SRB elements. At the end of 2004, the RSRM identified a use for HCFC 141b that must be added to this exemption. SEA worked with NASA HQ and the USEPA to include the RSRM HCFC 141b use on the current SSP exemption.



## Reduction of Hexavalent Chromium Exposure Limit

OSHA is under court order to reduce the PEL for CrVI. The current PEL is 100 µg/m<sup>3</sup> (ceiling) for chromic acid and chromates. In October 2004, OSHA proposed a new limit of 1 µg/m<sup>3</sup> as an 8-hour time weighted average (TWA). A final rule is expected in January 2006. SSP vendors that manufacture and use chrome-containing materials, such as conversion coatings and primers, could be significantly affected by this regulation.



## **Development of New National Emission Standards for Hazardous Air Pollutants**

The USEPA has begun development of a new NESHAP for surface coating and related operations on “Defense Land Systems and Miscellaneous Equipment.” The USEPA intends to include NASA facilities under this regulation. SEA members are participating in the development of this regulation to preclude any adverse impacts to such covered SSP operations as coating, stripping, and cleaning of the launch pads, crawlers, and mobile launch platforms.

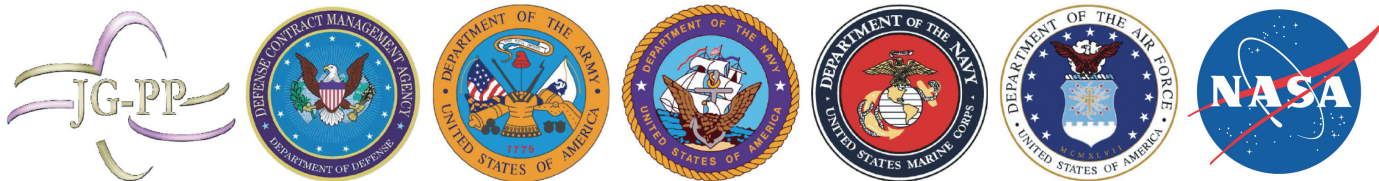
## **Brominated Flame Retardants**

BFRs are widely used as additives to plastic, rubber, and foam in the manufacture of electronic equipment, circuit boards, and polyurethane foam. One class of BFRs, polybrominated diphenyl ethers (PBDEs), includes materials that have been identified as persistent and bioaccumulative in the environment. Two of these, pentabromodiphenyl ether (penta-BDE) and octabromodiphenyl ether (octa-BDE) have been banned for electronics use by the EU and are no longer manufactured in the U.S. Regulations or manufacturing changes related to PBDEs could result in their replacement as flame retardants in many off-the-shelf materials used by the SSP. Changes in these materials could alter performance characteristics or compatibility with interfacing materials or systems. Identifying where PBDEs are used in SSP hardware could be difficult because vendors may not always know what flame retardant has been used in the manufacture of their product. The SEA Team is tracking regulatory activities involving BFRs and has begun to identify potential impacts to the program.

## **Lead-Free Electronics**

The EU is regulating the use of lead in electronics manufacturing because of concerns about exposure to lead in electronics parts after their disposal. Although RoHS and WEEE are EU directives, manufacturers of electrical, electronic, and electromechanical equipment outside Europe must also abide by this legislation if the equipment they produce is ultimately imported into an EU member state. RoHS officially takes effect on July 1, 2006, and details the prohibition and reduction of materials in certain products (e.g., mercury, Cd, and flame-retardant plastics). WEEE starts on August 13, 2005, and addresses the retrieval and recycling of electric and electronic devices. The intent of WEEE is to achieve a recycling target goal of 4 kg per person each year, no later than December 31, 2006. There are currently no similar regulations in the U.S. Many global commercial grade electronic manufacturers are gradually eliminating lead from some applications of solder and component finishes. This trend presents potential reliability and obsolescence concerns that must be addressed because substituted materials may not be compatible with existing SSP materials and environments

## 4. Interfaces and Collaborations



### Interfaces

SEA facilitates information sharing and interfaces with other NASA and external organizations. This teaming supports efficient identification and mitigation of environmental issues affecting the SSP and provides a forum to identify opportunities to leverage resources and develop collaborative efforts. SEA includes representatives of NASA Headquarters Environmental Management Division, the AP2 Office at KSC, and the Center and Prime Contractor Environmental offices. SEA also interfaces with the DoD Services, including the Air Force, Army, and Navy. SEA members participate directly in the SSP Integrated Logistics Panel (ILP), the NASA Clean Air Act Working Group (CAAWG), and the Joint Army Navy NASA Air Force (JANNAF) Interagency Propulsion Committee.

The SSP elements are participating in several interagency projects and have benefited from data collected in these collaborative efforts as shown in table 2.

Table 2. SEA interagency collaborations.			
Project	Description	SSP Participation	Status
Lead-free solder	JCAA*/JG-PP interagency project evaluating performance of lead-free solders.	SEA is actively participating.	Testing has been completed for thermal shock, vibration, salt fog, humidity, surface insulations resistance, and electrochemical migration.
Portable laser coating removal system	JG-PP/ESTCP** project to demonstrate and validate a coating removal system to replace use of solvents and abrasive blast media.	The orbiter is evaluating alternate systems and providing test panels.	Three hand held systems were tested. Follow on projects are being developed.
Nonchromate primers for aircraft exteriors	JG-PP study identified potential nonchromated replacements.	The orbiter flight-tested material.	Boeing is conducting field evaluations on Air Force aircraft.
Lockheed Martin/General Electric Shared Vision	Chromium free primer development	Lockheed Martin is participating in development.	Binder and inhibitor materials are in testing prior to formulation.

\*Joint Council on Aging Aircraft

\*\*DoD/USEPA Environmental Security Technology Certification Program

### Sustainability and Support to Follow-on Vehicles

The NASA HQ environmental office has a new focus on sustainability. Sustainability is the concept of meeting the needs of the present without compromising the ability of future generations to meet their needs. In conservation terms, sustainability refers to the use of a natural resource in a way that allows it to be renewed, and the environments' natural qualities maintained. SEA will play an active role in clarifying this approach and the implications of sustainability for the SSP and NASA.

SEA is also communicating to planners working on future vehicle programs the potential for materials that present obsolescence risks for SSP to be unavailable for use on new NASA vehicles.



### **NASA Acquisition Pollution Prevention Office**

The NASA AP2 Office, located at KSC, is responsible for identifying P2 needs and validating environmental technology solutions for use across the Agency. The AP2 Office is also NASA's representative to the JG–PP working group, ensuring a partnership for actively targeting P2 needs and migrating new technologies across NASA and the DoD Services. The AP2 Office uses a structured program and validated methodology to foster cooperation, leverage limited resources, avoid duplication of effort, and reduce total cost of ownership. The AP2 Office is represented on the SEA Team and supports the SSP effort in P2 and material replacement.

### **Interfaces With Other Agencies**

Working relationships have been developed with the Air Force Research Laboratory at Wright-Patterson Air Force Base, Dayton, OH; HQ AFSPC at Peterson Air Force Base, Colorado Springs, CO; and the Army Engineering Environmental & Logistics Oversight Office at Redstone Arsenal in Huntsville, AL. Members of these organizations attend SEA teleconferences and meetings and participate in technical discussions. SEA presented an overview of the SEA Team efforts at an Army in-process review hosted by the Redstone Arsenal in Huntsville, AL. SEA members also participate in industry-sponsored special topic groups such as the Aerospace Chrome Elimination Team (ACE) and Aerospace Industries Association (AIA) workshops.

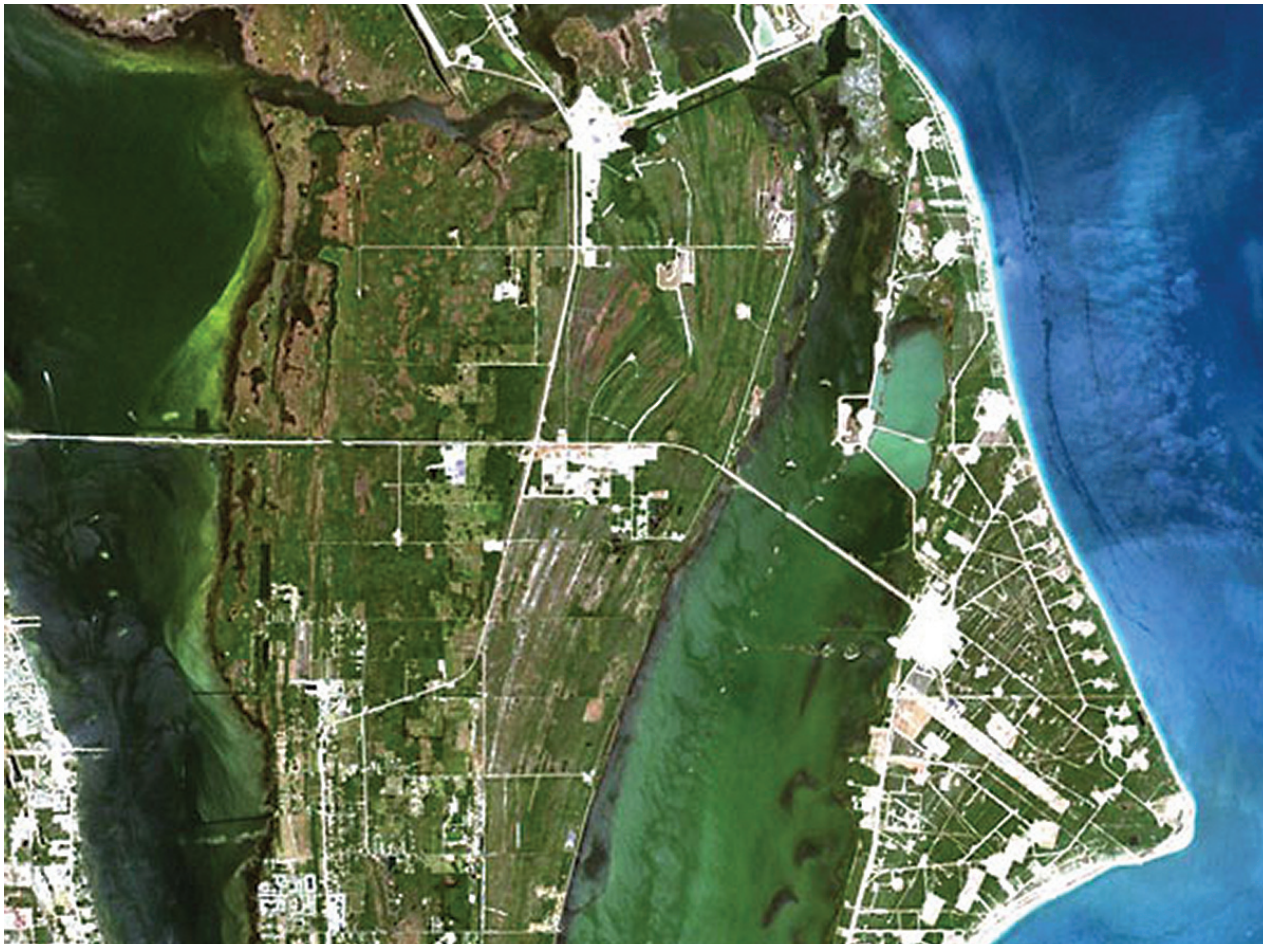
SEA works closely with the NASA AP2 Office and the interagency JG–PP group to identify opportunities to share information and partner with other government and industry organizations. JG–PP is a partnership between the Military Services, NASA, the Defense Logistics Agency, and the Defense Contract Management Agency that is chartered to reduce or eliminate hazardous materials or processes within the acquisition and sustainment communities.

## Air Force Space Command

SEA's collaborative work has expanded to include the HQ AFSPC. The manned and unmanned space programs share many of the same environmental challenges. SEA and HQ AFSPC have commenced a joint effort to identify common areas of environmental initiatives to eliminate and minimize the use of hazardous materials, reduce program total ownership costs, and increase program reliability. This collaboration also identified common processes and initiated joint projects incorporating pollution prevention requirements into one effort, thereby reducing cost, time, and duplication.

HQ AFSPC and SEA have exchanged information and experiences on environmental/sustainability acquisition as well as numerous analytical results from laboratory and field testing of environmentally preferred materials, thereby saving the government time and money with joint efforts and reducing duplication. These efforts have been very successful and HQ AFSPC has dramatically benefited while conducting field testing of coatings by utilizing SSP laboratory data shared by the SEA group. The HQ AFSPC missile program cut coating certification by an estimated 2 years and saved over \$4,000,000.

Due to the success of the above efforts, HQ AFSPC, NASA AP2, and SEA will be collaborating on additional initiatives in fiscal year (FY) 2005 to review corrosion control processes on launch facilities, to evaluate the use of laser coating removal processes, to continue with efforts to find suitable lead-free solders that can survive space conditions, and to find an environmental friendly isocyanate-free polyurethane to support joint space mission requirements.





# 5. Shuttle Environmental Assurance Issues and Risk Management

## Continuous Risk Management

Part of the SEA group’s charter is to identify environmentally driven materials-related technical issues that may affect SSP operations. These are evaluated to determine the possible impact to the SSP and potential mitigation strategies. Identified issues that represent environmentally driven material replacement challenges are assessed using the SSP risk matrix shown in figure 1 (National Space Transportation System (NSTS) 07700, Volume I) to evaluate the potential baseline risk to the program (i.e., the risk associated with the issue assuming no mitigation is done), as well as the current program risk.

The risk matrix plots the likelihood that an issue will affect the SSP (from “highly unlikely: 1/10,000” (1) to “very likely 1/10” (5)) against the consequence of the issue (from “temporary usage loss” (1) to “inability to support further Shuttle flight operations” (5)). Issues that fall in the red zone are those that present potentially high risks to the program, those in the yellow zone present medium risks, and the green zone identifies low program risks. SEA uses a continuous risk management process to identify, analyze, plan, mitigate, track, and control each issue. Mitigation plans are developed and implemented for identified issues, with an emphasis on issues that present high or medium risks to the SSP. SEA issues are also tracked and documented in the SSP Shuttle Integrated Risk Management Application (SIRMA).

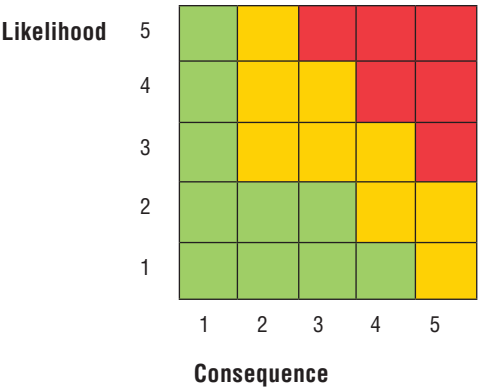


Figure 1. SSP risk matrix.

## Shuttle Environmental Assurance Issues

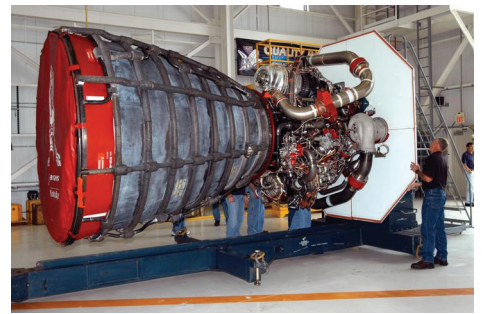
The SEA Team focuses on environmentally driven, materials-obsolescence issues for all SSP elements and systems. The SEA had 17 open technical issues in CY 2004. These issues included the potential loss of foams, solvents, coatings, metal finishes, and health and safety concerns posed by some materials used in SSP processing.

Table 3 lists the program elements affected by each SEA issue and shows the current program risk based on the SSP risk matrix. Mitigation plans are in place for all identified issues. Issues deemed to pose medium risk to the program are closely tracked and worked by the SEA Team. Table 4 describes the issues in more detail and presents current status and mitigation plans. Details are provided in section 6 regarding multielement collaborative efforts being pursued for three of these issues: CrVI in conversion coatings, CrVI in primers, and Cd in plating applications.



**Table 3. SEA issues and current program risk.**

SEA Issue	Elements Affected	Current Risk
HCFC 141b blowing agent	ET, SRB, Orbiter, RSRM	
TCA elimination (orbiter use)	Orbiter	
TCA elimination (RSRM use)	RSRM	
Cd replacement in plating applications	ET, Orbiter, RSRM, SSME, Ground support	
CrVI replacement in conversion coatings	ET, Orbiter, SRB, SSME, RSRM, FCE, Ground support	
CrVI replacement in primers	ET, Orbiter, SRB, SSME, RSRM, FCE, Ground support	
CrVI in alkaline cleaners	ET, FCE	
Chemical paint stripper alternatives	Orbiter	
Alternate dry-film lubricant (Lube-Lok®)	SRB	
High-VOC coatings	ET, Orbiter, SRB, RSRM	
Hypalon paint	SRB, RSRM	
Lead-free electronics	Orbiter, SRB, RSRM, SSME, FCE	
HAP inks	Orbiter	
Cleaning and verification solvents	Orbiter, ET, SSME	
MEK replacement	Orbiter, ET	
PFAS	Orbiter	
BFR	Orbiter, SRB, RSRM, SSME, FCE	Under evaluation



**Table 4. SEA issues, status, mitigation plans, and regulatory drivers.**

Title	Elements Affected	Issue	Status and Mitigation Plan	Regulatory Drivers
HCFC 141b blowing agent	ET, Orbiter, SRB, RSRM	<p><b>Risk:</b> The risk is the potential for HCFC 141b used in TPS foams to become unavailable and ET, orbiter, SRB and RSRM processing to be affected.</p> <p><b>Description:</b> HCFC 141b is the blowing agent used in much of the exterior insulating foam on the ET, interior areas of the orbiter, small closeout areas on the SRB exteriors, and in the RSRM nozzle plug. HCFC 141b is no longer generally available for purchase or import due to a ban by the USEPA.</p>	<p><b>Plan:</b> The mitigation plan is to maintain the exemption from USEPA that allows the use of HCFC 141b, and to include the newly identified RSRM use under that exemption.</p> <p><b>Status:</b> SSP holds an exemption from USEPA that allows the use of HCFC 141b on the ET, orbiter and SRB through 2009. SEA worked with USEPA to add the RSRM use to this exemption. This exemption must be renewed and justified annually.</p>	<p>Material: HCFC 141b.</p> <p>Class II ODS phased out of U.S. production and importation in 2003 (USEPA, 40 Code of Federal Regulations (CFR) Part 82).</p> <p>Class II ODS, phased out of most international production (Montreal Protocol).</p>
TCA elimination (orbiter use)	Orbiter	<p><b>Risk:</b> The risk is the potential for TCA used on the orbiter at KSC to become unavailable and for orbiter processing to be affected.</p> <p><b>Description:</b> Production and import of TCA was banned in 1995. TCA has been used on the orbiter for cleaning and surface preparation. In most procedures, TCA has been replaced with more environmentally friendly materials. TCA has not yet been replaced in critical orbiter rubber activation processes.</p>	<p><b>Plan:</b> The mitigation plan is to stockpile TCA that is available from the SSP and military sources and to screen materials to identify potential replacements.</p> <p><b>Status:</b> TCA has been stockpiled at KSC for orbiter use. The orbiter has screened potential replacements.</p>	<p>Material: TCA.</p> <p>Class I ODS, phased out of U.S. production and importation in 1995 (USEPA, 40 CFR Part 82).</p> <p>Class I ODS, phased out of most international production (Montreal Protocol).</p>
TCA elimination (RSRM use)	RSRM	<p><b>Risk:</b> The risk is the potential for TCA used on the RSRM to become unavailable and for RSRM processing to be affected.</p> <p><b>Description:</b> Production and import of TCA was banned in 1995. Most uses of TCA on the RSRM have been eliminated, but the RSRM still uses TCA in critical bonding applications.</p>	<p><b>Plan:</b> The mitigation plan is to purchase enough TCA under the RSRM's exemption to support RSRM processing through the life of the program.</p> <p><b>Status:</b> The RSRM had an exemption for continued purchase of TCA through CY 2004. The RSRM purchased enough TCA to support critical applications through the end of the program and is stockpiling the material at Alliant Techsystems (ATK)-controlled facilities.</p>	<p>Material: TCA.</p> <p>Class I ODS, phased out of U.S. production and importation in 1995 (USEPA 40 CFR Part 82).</p> <p>Class I ODS, phased out of most international production (Montreal Protocol).</p>
Cd replacement in plating applications	Orbiter, ET, RSRM, SSME, Ground support	<p><b>Risk:</b> The risk is the potential for Cd-plated components, particularly fasteners, to become unavailable and to affect ET, orbiter, RSRM, SSME, and ground support processing.</p> <p><b>Description:</b> The ET uses large numbers of Cd-plated parts, with smaller uses by the orbiter, RSRM, SSME, and ground support. These parts could become unavailable because manufacturers are increasingly reluctant to manufacture parts using the toxic materials required in the Cd plating process.</p>	<p><b>Plan:</b> The mitigation plan is to evaluate the potential risk and identify and test alternate materials.</p> <p><b>Status:</b> SEA is finalizing a study that assesses the risk to the SSP and discusses identification and testing of materials.</p>	<p>Material: Cd.</p> <p>HAP, a hazardous substance, and a hazardous waste (USEPA 42 (U.S. Code Annotated (USCA)) §7412(b)(1); USEPA, various regulations).</p> <p>Classified as a probable human carcinogen (B1) (USEPA Integrated Risk Information System (IRIS) summary).</p> <p>PEL is 5 µg/m<sup>3</sup> (OSHA).</p> <p>Classified as a known human carcinogen (National Toxicology Program (NTP), 10th Report on Carcinogens).</p> <p>International classification: Carcinogenic in humans (Group 1) (International Agency for Research on Cancer (IARC) Vol. 58, 1993).</p>

Title	Elements Affected	Issue	Status and Mitigation Plan	Regulatory Drivers
CrVI replacement in conversion coatings	Orbiter, ET, SRB, SSME, RSRM, Ground support, FCE	<p><b>Risk:</b> The risk is the potential for conversion coatings containing CrVI to become unavailable, affecting materials used in coating of flight hardware, ground support equipment (GSE), and coated parts supplied by vendors.</p> <p><b>Description:</b> Conversion coatings containing CrVI are used to inhibit corrosion and provide an adhesion base for paint systems. Safety and environmental regulations affecting CrVI use are expected to become more stringent, and manufacturers are becoming reluctant to manufacture products containing CrVI.</p>	<p><b>Plan:</b> The mitigation plan is to evaluate and monitor potential risks and to identify and test alternatives.</p> <p><b>Status:</b> SRB has implemented a chrome-free conversion coating. The orbiter and ET are evaluating alternatives. SEA is finalizing a study that assesses the risk of obsolescence and makes recommendations for mitigation.</p>	<p>Material: CrVI. HAP, a hazardous substance, and a hazardous waste (USEPA 42 USCA §7412(b)(1); USEPA, various regulations). Classified as a known human carcinogen (USEPA IRIS Summary), (NTP, 10th Report on Carcinogens). PEL is 52 µg/m3 as CrVI (OSHA). Proposed PEL is 1 µg/m3 as CrVI (OSHA). International classification: Classified as being carcinogenic in humans (Group 1) (IARC Vol. 49, 1990).</p>
CrVI replacement in primers	Orbiter, ET, SRB, SSME, RSRM, Ground support, FCE	<p><b>Risk:</b> The risk is the potential for primers containing CrVI to become unavailable, affecting materials used in coating of flight hardware, GSE, and coated parts supplied by vendors.</p> <p><b>Description:</b> Primers containing CrVI are used on SSP hardware to inhibit corrosion. Safety and environmental regulations affecting CrVI use are expected to become more stringent, and manufacturers are becoming reluctant to manufacture products containing CrVI.</p>	<p><b>Plan:</b> The mitigation plan is to evaluate and monitor potential risks and to identify and test alternatives.</p> <p><b>Status:</b> SRB has implemented a chrome-free replacement primer. The other affected elements continue to seek replacements. SEA is finalizing a study that assesses the risk of obsolescence and makes recommendations for mitigation.</p>	
CrVI replacement in alkaline cleaners	ET, FCE	<p><b>Risk:</b> The risk is the potential for chromated alkaline cleaners to become unavailable, affecting ET processing.</p> <p><b>Description:</b> The ET uses an alkaline cleaner that contains chromium to clean hardware prior to conversion coating and primer application. Safety and environmental regulations affecting CrVI use are expected to become more stringent, and manufacturers are becoming reluctant to manufacture products containing CrVI.</p>	<p><b>Plan:</b> The mitigation plan is to replace chromated alkaline cleaners.</p> <p><b>Status:</b> The ET is evaluating an alternate material. The evaluation includes large-scale immersion stability performance testing and identification of potential waste treatment impacts.</p>	
Chemical paint stripper alternatives	Orbiter	<p><b>Risk:</b> The risk is the potential for methylene chloride (MeCL) used on the orbiter to become unavailable and for orbiter processing to be affected.</p> <p><b>Description:</b> The orbiter relies on MeCL to strip coatings such as epoxy primers and polyurethane topcoats. MeCL is toxic and a HAP, and industrial users and material manufacturers are moving away from MeCL based materials. Many SSP paint-stripping applications already use environmentally friendly methods such as high-pressure water.</p>	<p><b>Plan:</b> The mitigation plan is to identify and test alternatives and to qualify new MeCL based products when currently used products become unavailable.</p> <p><b>Status:</b> The orbiter is continuing to test alternatives and is also evaluating a portable laser coating removal system that can replace chemical paint strippers in some applications.</p>	<p>Material: MeCl. HAP, a hazardous substance, and a hazardous waste (USEPA 42 USCA §7412(b)(1)) (USEPA, various regulations). Classified as a probable human carcinogen by the USEPA (USEPA IRIS Summary). Classified as reasonably anticipated to be a human carcinogen by the NTP (10th Report on Carcinogens). MeCl PEL 25 ppm (OSHA). International classification: Possibly carcinogenic to humans (Group 2B) (IARC Vol. 71, 1999).</p>

Title	Elements Affected	Issue	Status and Mitigation Plan	Regulatory Drivers
Alternate dry-film lubricant (Lube-Lok™)	SRB	<p><b>Risk:</b> The risk is the potential for the lead based solid film lubricant (Lube-Lok®) to become unavailable, affecting SRB processing.</p> <p><b>Description:</b> The current solid film lubricant is a two-part system with a bottom coat that consists of a lead-based ceramic bonded material. Industrial users and material manufacturers are moving away from lead-based materials, increasing the chance that the material will become unavailable. There is also a small risk of occupational exposure to lead.</p>	<p><b>Plan:</b> SRB plans to eliminate the use of the lead-based primer and use only the top coat portion of the system.</p> <p><b>Status:</b> SRB is testing a replacement for Lube-Lok®, a dry film lubricant, for unique high-load/low-shear applications. A qualification has been approved and preparation for testing has begun.</p>	<p>Material: Lead.</p> <p>HAP, a hazardous substance, and a hazardous waste (USEPA 42 USCA §7412(b)(1)), (USEPA, various regulations).</p> <p>Classified by USEPA as a probable human carcinogen (B1) (EPA IRIS Summary).</p> <p>PEL 50 µg/m³ (OSHA).</p> <p>International classification: Possibly carcinogenic in humans (Group 2B) (IARC Vol. 23, 1987).</p>
High-VOC coatings	Orbiter, ET, RSRM, SRB	<p><b>Risk:</b> The risk is the potential for high-VOC coatings to become unavailable, affecting ET, orbiter, RSRM, and SRB processing.</p> <p><b>Description:</b> High-VOC coatings are used throughout the SSP. These materials are heavily regulated and manufacturers are reducing the use of these materials, increasing the chance that these materials will become unavailable.</p>	<p><b>Plan:</b> The mitigation plan is to replace high-VOC coatings, including chromated primers.</p> <p><b>Status:</b> SRB has qualified a replacement. An orbiter replacement is in progress. The ET is testing alternate low-VOC primers.</p>	<p>Material: VOC.</p> <p>Some solvents in adhesives, like those used on tapes, are contributors to ambient ozone (smog), regulated in smog-prone areas (USEPA 40 CFR 50.9, 50.10).</p> <p>VOCs are usually flammable, and are subject to usage/storage restrictions (OSHA 29 CFR 1910.106).</p>
Hypalon paint	SRB, RSRM	<p><b>Risk:</b> The risk is the potential for occupational exposures to perchloroethylene and a violation of environmental regulations.</p> <p><b>Description:</b> Hypalon paint contains perchloroethylene, which is a hazardous and carcinogenic air pollutant. Hypalon paint is applied as a seal coat over the TPS of the SRB and to the exterior of the RSRM motor cases. When Hypalon is applied to the SRB TPS, it soaks into the TPS creating a hazardous waste when the SRBs are refurbished.</p>	<p><b>Plan:</b> The mitigation plan is to replace the material currently used on the SRB with a formulation that does not contain perchloroethylene. RSRM use of Hypalon does not create a hazardous waste and that application will not be replaced.</p> <p><b>Status:</b> The SRB is testing a perchloroethylene-free replacement for Hypalon paint. The qualification panels to test the new formulation are complete. Qualification is planned for 2005 and implementation is planned for 2006.</p>	<p>Material: Perchloroethylene.</p> <p>HAP, a hazardous substance, and a hazardous waste (USEPA 42 USCA §7412(b)(1)), (USEPA, various regulations).</p> <p>PEL 100 ppm (OSHA), 25 ppm (American Conference of Government Industrial Hygienists (ACGIH)).</p> <p>Classified by the NTP as reasonably anticipated to be a human carcinogen (NTP, 10th Report on Carcinogens).</p> <p>International classification: Probably carcinogenic in humans (Group 2A) (IARC Vol. 63, 1995).</p>
Lead-free electronics	Orbiter, RSRM, SRB, SSME, FCE	<p><b>Risk:</b> The risk is the potential for the SSP to receive components with lead-free solder that do not meet specifications and could affect the performance of flight hardware.</p> <p><b>Description:</b> In response to legislation in the EU, industry is trending toward reduction or elimination of lead in solders, board finishes, and other electronics applications. Although SSP purchasing contracts stipulate that vendors must notify SSP of any materials changes, it is possible that distributors may not know of changes made in the original equipment manufacturers' (OEMs') processes. The impact of lead-free solder use in flight hardware is unknown, but there have been cases of satellite performance adversely affected by a lead-free component.</p>	<p><b>Plan:</b> The mitigation plan is to evaluate potential risks, notify projects and logistics organizations, and remind vendors that lead-free components are not approved for use. Critical parts may require testing.</p> <p><b>Status:</b> The SSP projects have been notified of this issue. The orbiter and KSC logistics have sent notices to vendors. FCE is testing some parts and plans to obtain x-ray fluorescence equipment and achieve 100 percent testing.</p>	<p>Material: Lead.</p> <p>HAP, a hazardous substance, and a hazardous waste (USEPA 42 USCA §7412(b)(1)), (USEPA, various regulations).</p> <p>Probable human carcinogen (USEPA IRIS Summary).</p> <p>PEL 50 µg/m³ (OSHA).</p> <p>International classification: Possibly carcinogenic in humans (Group 2B) (IARC Vol. 23, 1987).</p> <p>International regulations: Banned from use in certain types of electrical and electronic equipment (EU Directives 2002/95/EC and 2002/96/EC).</p>

Title	Elements Affected	Issue	Status and Mitigation Plan	Regulatory Drivers
HAP inks	Orbiter	<p><b>Risk:</b> The risk is the potential for inks containing HAPS to become unavailable, affecting orbiter processing.</p> <p><b>Description:</b> Some HAPs are used as pigments or solvents in inks. Federal, Local and state authorities regulate emissions of HAPs. The orbiter uses small quantities of inks containing HAPs. Use of these inks poses a potential obsolescence risk as well as a small occupational risk to technicians.</p>	<p><b>Plan:</b> The mitigation plan is to replace HAP inks on the orbiter.</p> <p><b>Status:</b> The orbiter is evaluating candidate replacements.</p>	Material: Various HAPs. HAP (USEPA 42 USCA §7412(b)(1)).
Cleaning and verification solvents	Orbiter, ET, SSME	<p><b>Risk:</b> The risk is the potential for traditional cleaning and verification solvents to become unavailable and for ET, orbiter, and SSME processing to be affected.</p> <p><b>Description:</b> Chlorofluorocarbons (CFCs) were used in the SSP for precision cleaning and cleanliness verification in oxygen systems. Numerous cleaning solvent changes have been implemented over the years on the various elements.</p>	<p><b>Plan:</b> The mitigation plan is to identify, qualify, and implement alternatives.</p> <p><b>Status:</b> The ET has implemented HCFC 225. The orbiter has implemented several replacements and work is ongoing. The SSME has also implemented alternatives.</p>	Material: Chlorofluorocarbons (CFCs, Freons). Class I ODS, phased out of U.S. production and importation in 1995 (USEPA, 40 CFR Part 82). Class I ODS, phased out of most international production (Montreal Protocol).
MEK replacement	Orbiter, ET	<p><b>Risk:</b> The risk is the potential for MEK to become unavailable, affecting orbiter, and ET processing.</p> <p><b>Description:</b> MEK is a HAP and its replacement is desirable.</p>	<p><b>Plan:</b> The mitigation plan is to replace MEK.</p> <p><b>Status:</b> All SSP elements have worked on MEK replacements over the past 10 years and plan to address potential replacements as they emerge.</p>	Material: MEK. HAP (USEPA 42 USCA §7412(b)(1)). USEPA has proposed removing MEK from the federal HAP list. VOC (USEPA 40 CFR 51.100(s)). Flammable (OSHA 29 CFR 1910.106).
PFAS	Orbiter	<p><b>Risk:</b> The risk is the potential for materials containing PFAS to become unavailable, affecting orbiter processing.</p> <p><b>Description:</b> The orbiter has qualified a replacement for the Scotchgard™ waterproofing material used on the tiles. The replacement is a new formulation of Scotchgard™ without PFAS.</p>	<p><b>Plan:</b> Mitigation Plan is to find replacements for PFAS.</p> <p><b>Status:</b> The orbiter has implemented replacements.</p>	Material: PFAS. SNUR (USEPA 67 Federal Register (FR) 72854, 12/9/2002).
BFRs	Orbiter, ET, RSRM, SRB, SSME, FCE	<p><b>Risk:</b> The risk is the potential for BFRs used in SSP applications to become unavailable, and the possibility that vendors may replace these materials without notification.</p> <p><b>Description:</b> The EU discourages use of BFRs in electric and electronic components; some will be banned in most electrical equipment starting 7/1/2006. Studies in the U.S. are also examining these materials as persistent and bioaccumulative toxic substances. Some OEMs may be changing flame retardants as a result of this regulatory pressure. Although SSP purchasing contracts stipulate that vendors must notify the SSP of any materials changes, it is possible that distributors may not know of changes made in the OEMs' processes. Such changes could result in inadequate fire protection, incompatibility with interfacing materials, or off-gas/outgas problems.</p>	<p><b>Plan:</b> The mitigation plan is to identify SSP uses, evaluate risks and formulate a mitigation plan.</p> <p><b>Status:</b> The SEA Team is tracking regulatory activities involving BFRs and has begun to identify potential impacts to the SSP. The orbiter and FCE have begun to identify uses and potential impacts.</p>	Material: PBDE. Note: This is a class of several compounds. Regulations listed refer to worst case for one or more materials. Possible human carcinogen (USEPA IRIS Summary). Hazardous substance and a hazardous waste (USEPA, various regulations). Reasonably anticipated to be human carcinogens (NTP, 10th Report on Carcinogens). International classification: Possibly carcinogenic in humans (Group 2B) (IARC 1987). International regulations: Banned from use in certain types of electrical and electronic equipment (EU Directives 2002/95/EC and 2002/96/EC).



## 6. Shuttle Environmental Assurance Collaborative Study (Hexavalent Chromium and Cadmium)

### Concern

Two metals of special regulatory, human health, and environmental concern are CrVI and Cd. These materials are used extensively in Shuttle processing for different elements. The SEA Team is completing a multielement collaborative study to assess the obsolescence risk these materials pose and to suggest a mitigation plan.

CrVI is a heavily regulated toxic and carcinogenic substance. OSHA proposed a 100-fold reduction in the PEL for CrVI in October 2004. This reduction of the exposure limit for CrVI could increase production costs and introduce SSP supportability risks through accelerated materials obsolescence and vendor reluctance to continue using CrVI. More stringent environmental and safety regulations for CrVI are anticipated. As DoD and industry curtail the use of CrVI, these materials will likely become more expensive, could become unavailable, and present obsolescence risks to the SSP.

More stringent environmental and safety regulations for Cd are also anticipated. USEPA has designated Cd as a probable human carcinogen. The EU has legislated the phase-out of Cd in electronic applications by 2006. As DoD and industry curtail the use of Cd, these materials will likely become more expensive, have reduced suppliers, and present obsolescence risks.

### Approach

The SEA group undertook an initial scoping study to determine if the SSP should proceed with identifying and qualifying alternatives to chromate-containing primers and conversion coatings and Cd plated parts. The scoping study would also develop a proposal for a multi-element mitigation plan.

The decision whether to replace CrVI in conversion coatings and primers and to replace Cd in plating applications or to accept the potential obsolescence risk should be made by balancing the costs and benefits of replacing the materials against the costs, benefits, and risks of not replacing them. The remaining life of the Shuttle program and potential risks posed by continued reliance on these materials to follow-on vehicles should also be considered in these assessments.

### Space Shuttle Program Uses of Hexavalent Chromium and Cadmium

The SSP uses CrVI in a variety of applications on space flight hardware to prevent corrosion of aluminum substrates and enhance subsequent coating adhesion. Chrome conversion coatings and primers are the CrVI-bearing materials most widely used and also the most difficult to replace because of the stringent technical requirements they must meet. These materials are used in NASA and contractor facilities and by NASA's supplier base (table 5).

Table 5. SSP uses of chromated conversion coatings and chromated primers.					
Chromated Conversion Coatings			Chromated Primers		
Element	Material	Where	Element	Material	Where
ET	Iridite 14-2	ET interior and exterior	ET	DOD-P-15328D green wash primer	ET exterior surfaces
Orbiter	Alodine 1200S	Various	ET	TT-P-645A zinc chromate	ET exterior surfaces
Orbiter	Alodine 1132 Pens	Various	ET	Bonding primer	ET exterior surfaces
RSRM	Alodine 1200S	Multiple: Nozzle	Orbiter	Super Koropon®	Orbiter aluminum structure
RSRM	Alodine 1201	Multiple: Systems tunnel and nozzle	RSRM	463-06-0003-primer green bac 452 and x-306	Nozzle
RSRM	Chromium trioxide	Nozzle	SSME	Deft 03-GY-369 Deft 03-GY-385 Primer	SSME controller
SSME	Iridite 14-4	SSME	FCE	Primer	Various
SSME	Sodium dichromate	SSME	Ground support	LHB zinc chromated primer	KSC ground support
FCE	Alodine 600	Various			
FCE	Alodine 1132 Pens	Various			
Ground support	TT-P-1757Ag or y zinc chromate aerosol primer	GSE			



Cd usage on the SSP is element-dependent. Some elements have replaced Cd applications, while others still use Cd (table 6). Cd is of significant value to the performance of SSP elements. It provides protection to substrates when galvanic couples are created in assembling structures of dissimilar materials. Cd also provides lubrication to fasteners when high-strength parts are assembled and corrosion protection when applied to corrosion-sensitive materials.

Table 6. SSP uses of Cd plated parts.		
Element	Number of Cd Plated Parts	Applications
ET	Thousands of parts	Used on several substrates.
Orbiter	13 parts	Not changed regularly.
RSRM	Approximately 400 parts per motor	Alloy steel bolts and nuts, stainless steel bushings, alloy steel retainers for gaskets.
SSME	Small use, commercial off the shelf parts	Used in some GSE.
Ground	>2300 parts in inventory	Used in GSE and at facilities (e.g., pad). Not changed regularly.

## Risk

The Shuttle Program depends on the use of chrome conversion coatings, chrome primers, and Cd plated parts. Proposed OSHA regulations are expected to increase the challenges related to safely working with these materials. Other environmental restrictions and the increasing reduction of the use of these materials by industry and the DoD Services also increases the risk that the materials used by the SSP will become unavailable.

Obsolescence of these materials would have a significant impact on Shuttle supportability. Acceptable alternatives are not currently qualified for most Shuttle elements.

The likelihood that these materials will become obsolete will increase over time, but the overall risk to the Shuttle Program will be reduced as the last build dates for Shuttle hardware approach. It is also possible that identifying and qualifying a new material will not be complete before the processing that requires the material is complete. The risk to any new vehicle, especially a Shuttle-derived vehicle, will increase over time if no replacements are identified and qualified.

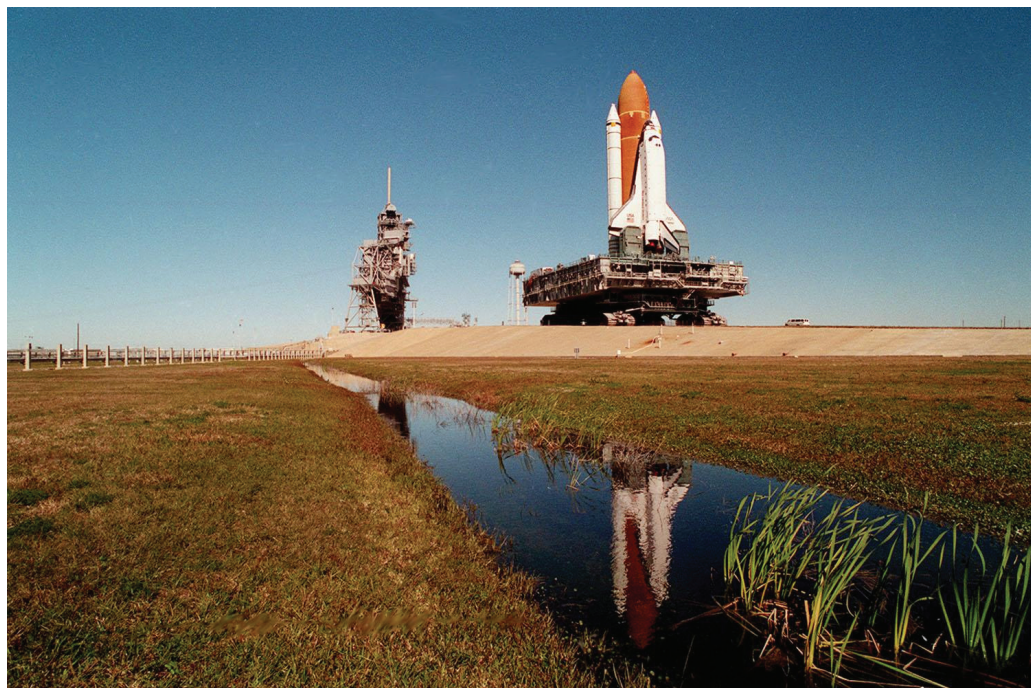
## Mitigation Options

There are three viable options available to mitigate the potential obsolescence risk posed by chrome conversion coatings, chrome primers, and Cd plated fasteners. Table 7 outlines the costs and benefits of each of these options: Accepting the potential obsolescence risk, stockpiling the material, or identifying and qualifying replacement materials.

## Mitigation Plans

SEA will provide a recommendation to the program on mitigating these obsolescence risks in CY 2005. A mitigation recommendation will consider the remaining life of the Shuttle and the risks and benefits to follow on vehicles.

The benefits of replacing these materials include obsolescence risk avoidance, reduction in occupational exposure and risk, and reduction in hazardous waste streams and the associated costs. Future vehicles will also directly benefit from the identification of replacements for materials containing CrVI and Cd, because these materials may not be available for use on new NASA vehicles. Costs of replacement will include the cost of screening identified materials and down selecting replacement(s) and qualifying the replacements for flight.



**Table 7. Qualitative Costs and Benefits of Mitigation Options.**

<b>Alternative</b>	<b>Cost</b>	<b>Benefit</b>
Accept risk	<ul style="list-style-type: none"> <li>• Major impact to Program if materials become unavailable while vehicle is still being processed</li> <li>• Current and increased future costs associated with waste disposal</li> <li>• Current and increased future costs associated with record keeping</li> <li>• Current and increased future costs associated with personal protective equipment and monitoring</li> <li>• Potential occupational exposure to carcinogenic and toxic materials</li> <li>• Liability (vendors, occupational, and environmental)</li> <li>• Cost to monitor vendors</li> </ul>	<ul style="list-style-type: none"> <li>• No replacement cost</li> </ul>
Stockpile	<ul style="list-style-type: none"> <li>• Cost to store materials</li> <li>• Cost to monitor shelf-life</li> <li>• Major impact to Program if shelf-life not adequate and materials become unavailable while vehicle is still being processed</li> <li>• Current and increased future costs associated with waste disposal</li> <li>• Current and increased future costs associated with record keeping</li> <li>• Current and increased future costs associated with personal protective equipment and monitoring</li> <li>• Potential occupational exposure to carcinogenic and toxic materials</li> <li>• Liability (vendors, occupational, and environmental)</li> </ul>	<ul style="list-style-type: none"> <li>• No replacement cost</li> </ul>
Qualify replacement	<ul style="list-style-type: none"> <li>• Cost to screen alternatives</li> <li>• Cost to qualify replacement</li> <li>• Cost to change processes</li> <li>• Risk that no alternative will qualify</li> <li>• Risk that processing will be complete before alternative is qualified</li> </ul>	<ul style="list-style-type: none"> <li>• Eliminate obsolescence risk</li> <li>• Reduce waste and waste disposal costs</li> <li>• Reduce record keeping cost</li> <li>• Reduce personal protective equipment and monitoring costs</li> <li>• Reduce potential for exposure to carcinogenic and toxic materials</li> <li>• Reduce liability</li> <li>• Support NASA and contractor pollution prevention goals</li> <li>• Support NASA response to Executive Order 13148</li> <li>• Support new vehicle(s)</li> <li>• Enable leveraging with DoD</li> <li>• Sustain human capital and engineering through transition</li> </ul>

## 7. Pollution Prevention Successes

### Stratospheric Ozone Award

The SEA Team received a USEPA Stratospheric Ozone Award in April 2004 for the replacement of TCA and CFCs in critical Shuttle operations.

#### Replacement of TCA and CFCs in Critical Shuttle Operations

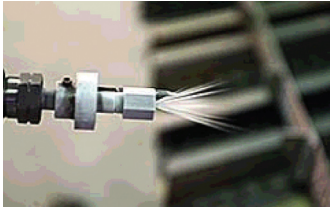
**Summary:** With support from the SEA initiative, NASA and its contractors have replaced ODSs. Accomplishments include the following:

- The RSRM/ATK Thiokol reduced use of TCA by 97 percent since 1990, and tests are scheduled to qualify as many remaining applications as technically feasible.
- The orbiter/Boeing eliminated TCA in 247 procedures, and identified candidates for remaining critical applications, replaced CFC-113 with alternatives at Palmdale and KSC, and is working with an interagency team to demonstrate coating removal systems using hand-held portable lasers.
- The ET/Lockheed Martin replaced CFC-113 with HCFC-225 for most surface verification solvent applications.
- The SSME/Rocketdyne replaced ozone-depleting cleaning and verification solvents.
- The SRB eliminated TCA use in 1994.
- The CFC-113-replacement team (NASA, United Space Alliance (USA), Boeing, Wiltech) at KSC implemented Vertrel XF for use in the early cleaning process and a liquid oxygen (LOX) compatible material (hydrofluoroether (HFE)-7100) for final verification.
- Hamilton Sundstrand/FCE eliminated Freon perfluorocarbon (PFC) in precision cleaning high-pressure oxygen systems.

### The Kennedy Space Center Chemical Commodity Reutilization Program

Disposal of unused chemicals can create hazardous wastes. The SSP partners with aviation-related small businesses and nonprofit associations who can make use of these materials, such as the Port Canaveral Fishermen's Association. USA Environmental Management coordinates this Chemical Commodity Reutilization Program. Since November 2002, over \$600,000 worth of chemicals have been reutilized. This program has avoided the disposal costs associated with more than 12,000 kilograms (26,400 pounds) of hazardous waste and 16,000 kilograms (35,200 pounds) of nonhazardous waste.





## Liquid Nitrogen Process

USA Materials and Process Engineering at KSC has been working with a new technology called NitroJet™ that uses liquid nitrogen to cut materials and remove coatings. NitroJet™ uses a system of cooling and pressurizing liquid nitrogen, creating an ultra-high-velocity jet of supercritical liquid nitrogen. NitroJet™ can trap the hazardous materials being cut or removed with a vacuum capture system, and no secondary waste stream is created. Because nitrogen is inert, it can be used with flammable or explosive materials.

The NitroJet™ technology was used to remove the booster trowelable ablative (BTA) from the solid rocket motor aft structures. Previous attempts to remove this material used mechanical methods or hydrolasing of the materials. Both of these methods are hazardous to the hardware and/or the personnel and could not support the Shuttle's return to flight schedule.

## Chemical Fingerprinting

RSRM has encountered situations where raw materials (e.g., polymers, adhesives, and cleaners) met specification but were different enough chemically to cause manufacturing or flight performance issues. These differences resulted from unplanned or unknown vendor process changes, contamination, or changes at subtier suppliers. ATK Thiokol Propulsion instituted a material-“fingerprinting” program to screen end items and process materials and provide ongoing “insurance” that nothing creeps into the processes.

A chemical fingerprint can be used to identify a material, to differentiate it from similar looking materials, or provide a trail to its source. ATK Thiokol Propulsion initiated the fingerprinting program in FY 1998. Since then, more materials have been fingerprinted and the database expanded, personnel trained, analytical methods developed, and the system enhanced. Ten to 12 additional materials will be fingerprinted per year through FY 2006.

ET also has a fingerprinting program that, over the years, has characterized a broad range of materials including urethane and isocyanurate foams, adhesives, composites, primers, solvents, and cleaners. The ET program uses fingerprinting to monitor the consistency of incoming materials in support of ET production and new material qualifications, to diagnose material performance problems, and to evaluate alternate formulated products and raw materials. ET is currently planning a critical requirements task that will be dedicated to fingerprinting all ET materials. SRB and SSME are beginning to evaluate fingerprinting methods.



## 8. Material Replacement Projects

### Parts Washers

The NASA AP2 Office identified the need for environmentally preferable parts washers. The scope of the project was to test selected parts washers that met performance guidelines set by stakeholders and develop a “Consumer’s Guide.” The project also included a comparative analysis of parts washers including cleaning efficiency.

The NASA AP2 Office completed testing on nine part washers at five NASA Facilities (KSC, MSFC, Wallops Flight Facility (WFF), Goddard Space Flight Center (GSFC) and Michoud Assembly Facility (MAF)). The Rochester Institute of Technology will be testing the cleaning efficiency of 32 environmentally preferable chemistries along with four benchmark chemistries (MEK, isopropyl alcohol (IPA), acetone, and mineral spirits).

Testing and evaluation will be completed in CY 2005, at which time a “Consumer’s Guide” to alternative part washers will be published and distributed to all NASA Centers.

### Portable Laser Coating Removal System

Coating systems are typically removed using hazardous and corrosive chemicals or abrasive blast media. An alternative to these methods would reduce occupational exposures and the use of hazardous materials.

The JG–PP worked with the DoD/USEPA ESTCP to demonstrate and validate a coating removal system using a portable hand-held laser. A portable laser coating removal system (PLCRS) removes coatings with minimal environmental and safety impact and no harmful chemicals to purchase, store, and dispose. The PLCRS process is time and cost efficient with minimal prepaint preparation. Strip rates are acceptable for small depaint areas and it is effective at coating removal in otherwise difficult areas such as corners and concave surfaces.

Three hand-held systems were tested. After initial testing, two of the systems may be of future interest to NASA in the following application areas: Stripping small areas of paint from composite and aluminum surfaces during Shuttle refurbishment between flights, small area stripping of SRB components, and as a replacement for glove-box stripping applications of small parts that have complex geometries.

Field-testing was conducted at Wright Patterson Air Force Base in August of 2004. KSC and Glenn Research Center sent personnel to view and test the hand-held laser systems on test coupons. NASA personnel stripped various components including aircraft components and a Shuttle tile cavity mock-up. The lasers worked well for all applications and the group will be deciding how best to pursue NASA follow-on projects now that the DoD PLCRS project is drawing to an end. The group decided that two areas for laser depainting would be pursued. The first area is Shuttle and flight hardware, which will be dependant on funding from various Shuttle groups. The second area (which is already partially funded) will focus on GSE. Projects should be underway by the end of 2005.



## Alternative Low Emission Surface Preparation/Depainting Technologies for Structural Steel

NASA and AFSPC own and maintain a number of facilities/structures with metallic structural and nonstructural components in highly and moderately corrosive environments. Regardless of the corrosivity of the environment, all metals require periodic maintenance activity to guard against the onslaught of degradation and thus ensure that structures meet or exceed design life. The standard practice for protecting metallic substrates in atmospheric environments is the application of an applied coating system. Applied coating systems work via a variety of methods (e.g., barrier, galvanic, and and/or inhibitor) and adhere to the substrate through a combination of chemical and physical bonds.

To achieve a substrate condition suitable for the application of a coating system, a variety of technologies may be used compliant to a variety of standards. The cleanliness requirements for carbon steel (the dominant substrate for facilities, structures, and equipment) as a function of the aggressiveness of the environment and substrate profile dictates the use of abrasive media. Since the banning of siliceous sand across NASA and AFSPC due to its health and environmental issues, slag has become the media of choice for surface preparation of carbon steel.

While slag media achieves an acceptable surface profile and level of cleanliness, a number of “new” factors must now be considered when selecting an abrasive media or surface preparation technology. These include environmental, health and safety issues, and cost and waste generation.

The NASA AP2 Office began this project to identify, evaluate, and approve alternative surface preparation technologies. Materials and processes were evaluated with the goal of selecting those processes that will improve corrosion protection at critical systems, facilitate easier maintenance activity, extend maintenance cycles, eliminate flight hardware contamination, and reduce the amount of hazardous waste generated across NASA and AFSPC. Laboratory and field testing will begin in 2005.

## Alternatives to Aliphatic Isocyanate Urethanes on Structural Steel

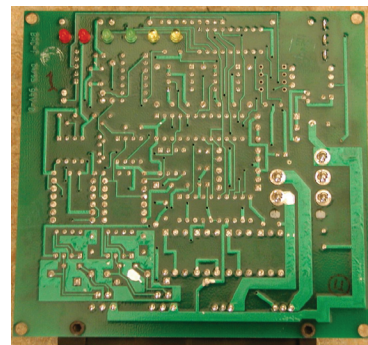
Aliphatic urethanes coatings are extremely tough, chemical resistant, colorfast coatings with excellent gloss retention. These coatings are typically used within the aerospace industry on aircraft bodies, aircraft hanger floors, and support equipment. These coatings are typically two component systems consisting of a polyester or acrylic polymer and an aliphatic isocyanate curing agent. The combination of these two ingredients and the resulting chemical reaction cures the coating.

As a result of the widespread use of isocyanate urethanes (IU) and the increasing concerns in the EHS and industrial hygiene arena, the NASA AP2 Office and HQ AFSPC embarked on a project aimed at identification and demonstration/validation of suitable alternatives to IUs for use on structural steel.

While identifying isocyanate-free coatings, the NASA AP2 Office also ensured that alternatives were low-VOC and contained no hazardous materials, but provided protection equal to IUs. All materials were procured and the preparation of coupons for laboratory testing completed. Laboratory and field-testing will begin in 2005.

## Joint Council on Aging Aircraft/Joint Group on Pollution Prevention: Lead-Free Solder Project

Current and future space and defense systems face potential risks from the continued use of tin-lead solder including: Compliance with current environmental regulations, concerns about potential environmental legislation banning lead-containing products, reduced mission readiness, and component obsolescence with lead surface finishes. For example, the USEPA has lowered the toxic chemical release-reporting threshold for lead to 100 pounds. Overseas, the WEEE and the RoHS directives in Europe and similar mandates in Japan have instilled concern that a legislative body will prohibit the use of lead in aerospace/military electronics soldering.



Any potential banning of lead compounds could reduce the supplier base and adversely affect the readiness of missions led by NASA and DoD. However, before considering lead-free electronics for system upgrades or future designs, it is important to know whether lead-free solders can meet system requirements. No single lead-free solder is likely to qualify for all defense and space applications; therefore, it is important to validate alternative solders for discrete applications.

As a result of the need for comprehensive test data on the reliability of lead-free solders, a partnership was formed between the DoD, NASA, and several OEMs to conduct solder-joint reliability (laboratory) testing of three lead-free solder alloys on newly manufactured and reworked circuit cards to generate performance data for high-reliability (IPC Class 3) applications.

While work has been done to determine lead-free reliability for class 1 and class 2 applications, there has been little comprehensive data published on class 3 surface mount assemblies. To resolve the need for better understanding of how lead-free solders perform under harsh environments, a joint project was initiated by the DoD's JG-PP in 2001 to characterize the performance of lead-free solders as potential replacements for conventional tin-lead solders used on printed wiring assemblies (PWAs).

The intent of the study is to test for functional (electrical) reliability of representative test boards assembled and reworked with lead-free solders. "Representative" was defined as circuits now on defense/space systems (e.g., surface mount technology, plated through holes, and mixtures of old and new components). In addition, a portion of the test vehicles built for the lead-free solder project will test the effectiveness of repairing lead-containing printed wiring boards with lead-free solder.

Reliability testing includes thermal and mechanical shock, vibration,  $-55$  to  $+125$  °C and  $-20$  to  $+80$  °C thermal cycle procedures per IPC-9701, salt fog, humidity, surface insulation resistance, electrochemical migration, and combined environments (concurrent vibration/thermal cycling). Testing has been completed for the thermal shock, vibration, salt fog, humidity, surface insulations resistance, and electrochemical migration.



## **Lead-Free Soldering for Space Applications Body of Knowledge**

MSFC asked the NASA AP2 Office to develop a body of knowledge (BOK) regarding lead-free solder. The BOK will serve as a guidance document that will assist NASA in determining areas of risk associated with class 3 high-reliability electronics and the transition to lead free by analyzing lead-free test programs, university lead efforts, and supply issues associated with electronic components, systems, and subsystems exposed to the harsh environmental conditions of space exploration missions.

Specifically, the AP2 Office is to perform a technology readiness overview of lead-free solder; summarize assembly and material characterization testing data; identify experts within government, NASA, industry and academia; identify technical gaps in the understanding of lead-free solder (with an emphasis on reliability testing relevant to space hardware); identify risks to NASA associated with the commercial sector's transition to lead-free and the possibility of converting to lead-free, and recommend mitigation strategies for each risk.

## **Environmentally Preferred Coatings for Launch Structures**

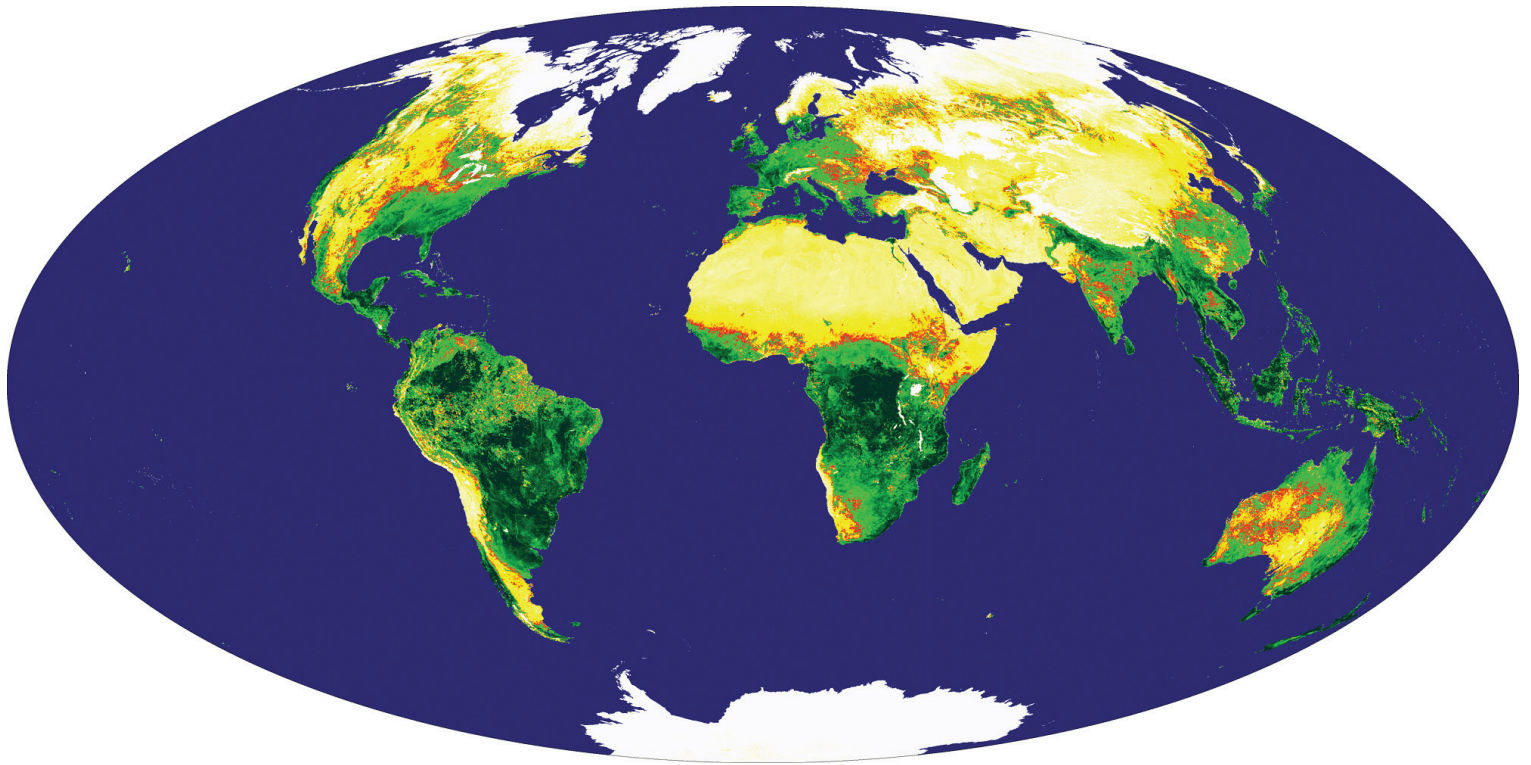
The AFSPC incorporated Shuttle program requirements in a study to evaluate off the shelf environmentally preferred coatings to protect launch structures. Launch structures are exposed to severe conditions that include launch gases and extremely corrosive coastal atmospheric conditions. Current coatings require constant rework and repair utilizing hazardous materials and generating a constant hazardous waste stream. HQ AFSPC integrated NASA Kennedy coating requirements along with the military requirements at no cost to NASA. In FY 2004, HQ AFSPC completed the environmental opportunity assessment and coupon testing at the NASA corrosion control facility is scheduled in FY 2005.

## **Fiber Optic Detector for Hydrazine**

HQ AFSPC also included NASA and SEA in their initiative to develop a fiber optic detector to determine the presence of hydrazine. Current technologies are increasingly unreliable because of the indication of false positives. An ESTCP project has been developed and forwarded for review/funding by HQ AFSPC with NASA as a joint partner. Defending of the proposal is expected in FY 2005.

## **Microwave Technology to Treat Hypergolic Fuels**

HQ AFSPC has also collaborated with NASA and SEA on the demonstration/validation of microwave technology to treat hypergolic fuels. This effort has proved to destroy 99.997 percent of the waste stream, eliminating the hazardous waste disposal. Currently, full-scale design is underway and manufacturing/installation of the system is expected in FY 2005 and FY 2006.



**Global Vegetation Index:** This global snapshot by the MODIS satellite shows where green foliage is being produced by land plants (green and dark green show greater productivity; yellow shows little or no production; red is a boundary zone), as the terrestrial biosphere “breathes in” carbon dioxide for photosynthesis (MODIS Land Group, Goddard Space Flight Center).

## 9. Lessons Learned and Shuttle Environmental Assurance Support to Shuttle Transition

### Lessons Learned

The SEA Team has expertise that can help future NASA programs based on the team's experience in addressing environmentally driven obsolescence and regulatory threats to the SSP.

Any new program should plan and design for environmental sustainability. NASA and the SSP can benefit from collaboration with HQ AFSPC on an environmental/sustainable acquisition process. It should also establish a working group composed of environmental and materials experts that can identify regulatory activities that could result in obsolescence and work together to develop mitigation approaches.

In designing new vehicles and associated equipment, use of the following materials should be avoided:

- Ozone depleting chemicals such as TCA (currently used by the orbiter and RSRM) and HCFC 141b (currently used by the ET, orbiter, SRB, and RSRM).
- Heavy metals such as CrVI (prevalent in primers, conversion coatings, and other materials), lead (used by the SRB as a dry film lubricant), and Cd plating (used on fasteners).
- Adhesives, coatings, and other materials with high-VOC content.

### Support to Shuttle Transition Planning

SEA members have participated in the Integrated Space Operations Summit (ISOS) and SSP transition planning activities to provide input based on lessons learned, environmental and materials experience, and a mission execution perspective.

Input included the recommendation to establish an Agency-level environmental management team composed of representatives from NASA HQ, Centers, the Shuttle Program, and project elements to develop and implement an environmental transition plan.

SEA will continue to provide recommendations in SSP planning and work activities relating to the mission execution and transition work. SEA will identify any issues that would increase risk to mission execution and aid in developing efficient environmental approaches to the transition efforts.



## 10. Summary and Benefits to the Space Shuttle Program and the National Aeronautics and Space Administration

SEA provides a forum for the Shuttle environmental/materials community to address common problems. A proactive, cooperative approach to environmental obsolescence drivers saves resources and time and reduces the risk to the program associated with the loss of materials.

Replacement of hazardous materials has benefits in addition to the elimination of obsolescence risks. Hazardous materials require special handling, permitting, and documentation. Their use may create a hazardous waste stream and the potential for occupational exposures. Reducing the use of hazardous materials reduces these costs. Future vehicle programs will also directly benefit from the identification of materials that may present obsolescence risks for the SSP because these materials may not be available for use on new NASA vehicles.

SEA has benefited the SSP by providing notice and technical support concerning vendor changes and materials concerns, sharing material replacement data and working mitigation efforts, bringing potential issues and risks to management and other technical forums, interfacing with the DoD, working with regulators to minimize the adverse impact of regulatory restrictions on the SSP, and maintaining essential use exemptions.

The SSP elements and supporting organizations have made progress in identifying and mitigating various environmental and material obsolescence concerns to reduce risk to the program. SEA will continue to proactively identify regulatory issues and other obsolescence drivers that may affect the SSP and to work on technical issues determined to pose risk to the program.



## Appendix A: Shuttle Environmental Assurance Team

SEA is a multidisciplinary team of NASA and Shuttle civil servants and contractors with expertise in materials science, engineering, logistics, systems integration, pollution prevention, environmental engineering, and environmental regulations and impacts. All of the Shuttle elements and major hardware and operations support contractors are active members of the team.

SEA also has active participation from NASA Headquarters, NASA Centers' Environmental Offices, the NASA AP2 Office, the ILP, the Common Materials and Specifications Management Group (CMSMG), Safety and Mission Assurance (S&MA), the NASA CAAWG, and the NASA Electrical, Electronics and Electromechanical Parts Working Group. Table 1 lists the organizations and contractor companies that participate in SEA.

Table A1. SEA organizations and contractors.	
<b>NASA Centers</b>	
Marshall Space Flight Center, Huntsville, AL	PSE&I Office ET Project Office RSRM Project Office SSME Project Office SRB Project Office Safety and Mission Assurance NASA Clean Air Act Working Group Engineering Directorate Environmental Engineering Department Electrical, Electronics and Electromechanical Parts Working Group
Kennedy Space Center, FL	Materials & Processes Grounds Operations Environmental Management Office (EMO) Integrated Logistics Panel NASA Acquisition Pollution Prevention Office
Johnson Space Center, TX	Orbiter Project Office Materials and Processes Engineering Flight Crew Equipment
Stennis Space Center, MS	EMO
Michoud Assembly Facility, LA	NASA Resident Office
NASA Headquarters, Washington DC	Environmental Management Division
<b>SSP Contractors and other federal organizations</b>	
Canoga Park, CA	Pratt and Whitney Rocketdyne, inc. (SSME)
Brigham City, UT	ATK Thiokol Propulsion (RSRM)
Huntington Beach, CA	Boeing (Orbiter)
Windsor Locks, CT	Hamilton Sundstrand Space Systems (FCE)
Michoud Assembly Facility, LA	Lockheed Martin (ET)
Kennedy Space Center, FL	United Space Alliance (SRB, GSE, orbiter, logistics, materials and processing (M&P)) International Trade Bridge (AP2)
Marshall Space Flight Center, AL	United Space Alliance (PSE&I) ATK Thiokol (RSRM) International Trade Bridge, Inc. (ITB) (PSE&I) Hernandez Engineering
Peterson Air Force Base, CO	HQ AFSPC

## Appendix B: Acronyms and Abbreviations

ACE	Aerospace Chrome Elimination Team
ACGIH	American Conference of Governmental Industrial Hygienists
AFSPC	Air Force Space Command
AIA	Aerospace Industries Association
AP2	Acquisition Pollution Prevention
ATK	Alliant Techsystems
BFR	brominated flame retardant
BOK	Body of Knowledge
BTA	booster trowelable ablative
CAAWG	Clean Air Act Working Group
Cd	cadmium
CFC	chlorofluorocarbon
CFR	Code of Federal Regulations
CrVI	hexavalent chromium
CTG	Control Techniques Guidelines
CMSMG	Common Materials Specifications Management Group
CY	calendar year
DoD	Department of Defense
EHS	environmental, health, and safety
EMO	Environmental Management Office
ESTCP	Environmental Security Technology Certification Program
ET	external tank
EU	European Union
EUE	Essential Use Exemption

FCE	flight crew equipment
FR	Federal Register
FY	fiscal year
GSE	ground support equipment
GSFC	Goddard Space Flight Center
HAP	hazardous air pollutant
HCFC	hydrochlorofluorocarbon
HFE	hydrofluorether
HQ	Headquarters
IARC	International Agency for Research on Cancer
ILP	Integrated Logistics Panel
IPC	IPC: Association Connecting Electronics Industries
IRIS	Integrated Risk Information System
ISOS	Integrated Space Operations Summit
IPA	isopropyl alcohol
ITB	International Trade Bridge, Inc.
IU	isocyanate urethanes
JANNAF	Joint Army Navy NASA Air Force Interagency Propulsion Committee
JCAA	Joint Council on Aging Aircraft
JG-PP	Joint Group on Pollution Prevention
KSC	Kennedy Space Center
LOX	liquid oxygen

MAF	Michoud Assembly Facility
MeCL	methylene chloride
MEK	methyl ethyl ketone
M&P	materials and processing
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NESHAP	National Emission Standards for Hazardous Air Pollutants
NSTS	National Space Transportation System
NTP	National Toxicology Program
octa-BDE	octabromodiphenyl ether
ODS	ozone-depleting substance
OEM	original equipment manufacturers
OSHA	Occupational Safety and Health Administration
P2	pollution prevention
PBDE	polybrominated diphenyl ether
PEL	personal exposure limit
penta-BDE	pentabromodiphenyl ether
PFC	perfluorocarbon
PFAS	perfluoroalkyl sulfonates
PLCRS	portable laser coating removal system
PSE&I	propulsion systems engineering and integration
PWA	printed wiring assemblies
RSRM	reusable solid rocket motor
RoHS	Restrictions on Hazardous Substances

S&MA	Safety and Mission Assurance
SEA	Shuttle Environmental Assurance
SIRMA	Shuttle Integrated Risk Management Application
SNUR	Significant New Use Rule
SRB	solid rocket booster
SSME	Space Shuttle main engine
SSP	Space Shuttle Program
TCA	1,1,1-trichloroethane (methyl chloroform)
TPS	thermal protection system
TWA	time weighted average
U.S.	United States
USA	United Space Alliance
USCA	United States Code Annotated
USEPA	United States Environmental Protection Agency
µg/m <sup>3</sup>	microgram per cubic meter
VOC	volatile organic compound
WEEE	waste electrical and electronic equipment
WFF	Wallops Flight Facility

